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Resilient design of recharging station networks for electric transportation vehicles

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Laboratory for Intelligent Process Systems

INL

Overview

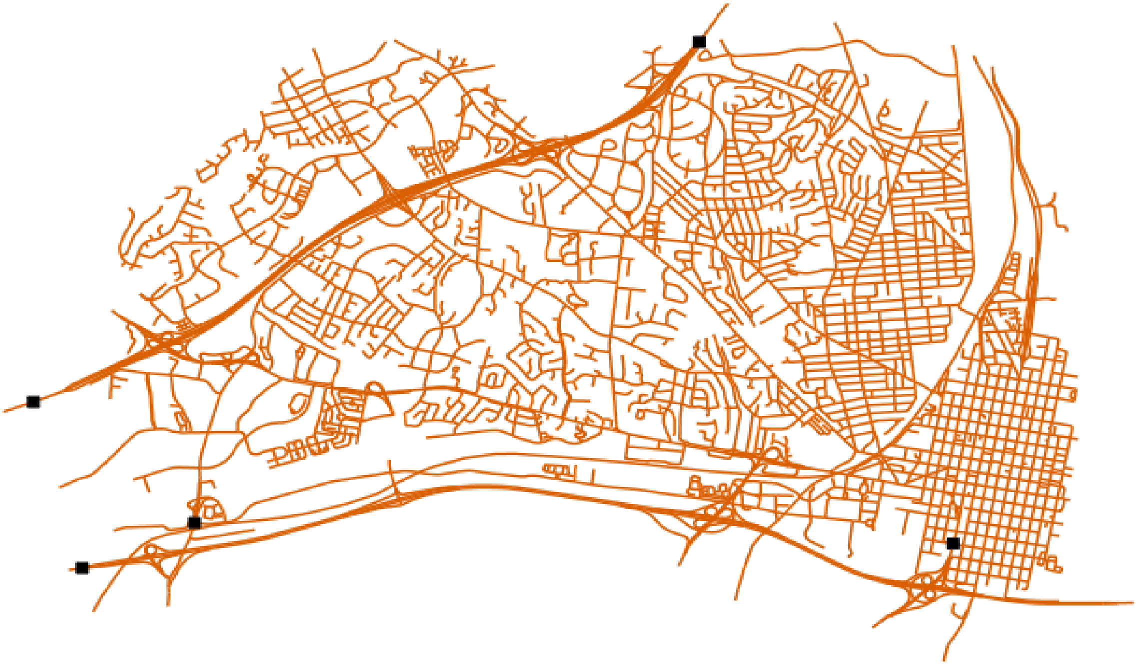
- Background
- Case study
- Problem statement
- Method
- Results
  - In simulation
  - In pilot-scale plant
- Future

Background

- Move to greener society
- Transportation: electric vehicles
  - Pollution is concentrated, easier to handle
  - Positive effects in urban environment
- Recharging of vehicles
  - SmartGrid solutions (plug-in)
  - Battery replacement (get charged battery)
- Requires new infrastructure:
  - Battery replacement facilities

Case study

- Alexandria, VA
  - 2620 junctions (nodes)
  - 3653 road links (arcs)



Problem statement

Given a city road network

- place facility locations in an optimal fashion
- while accounting for eventual failure of nodes, edges and facilities

Method

Method (facility interception model)

1. Compute expected traffic
2. For given traffic, find optimal locations

Practical solution

1. TRANSIMS (TRansportation ANalysis SIMulation System)
2. Mixed Integer Program

Method

Original formulation: no failures

x_j = 1 if a service station is located on node *j (1..2620)*

= 0 otherwise

y_p = 1 if a service station is located on path *p (1..114941)*

= 0 otherwise

$f_{total} = \Sigma_{p \in P} f_p$

$J = 1 / f_{total} . \Sigma_{p \in P} f_p \cdot y_p$

$\Sigma_{j \in p} x_j \geqslant y_p$

Method

Extended formulation for failures:

$J \quad = \quad 1 / f_{total} \,.\, \Sigma_{p \in P} f_p \cdot y_p \,.\, \rho_p$

Failure probability of path: ρ_p

$\rho_p = \quad 1 - (p_a \cdot m_{a,p} + p_n \cdot m_{n,p} + p_{s,p})$

$p_{s,p} = p_s^{\#stations}$

$\quad = \Sigma_m \; z_{p,m} \cdot p_s^m \qquad m = 1..\#m_{n,p}$

$\Sigma_m z_{p,m} \leqslant 1$

Implementation

Platform:

- General Algebraic Modeling System (GAMS)
- ILOG CPLEX solver

Full problem:

For 20 service stations

- $\Sigma_j \, x_j \leqslant m_{s,total}$
- 2298820 variables
  - x_j (2620)
  - y_p (114941)
  - $z_{p,m}$ (114941 paths x maximally m=20 stations)
- 22983 constraints

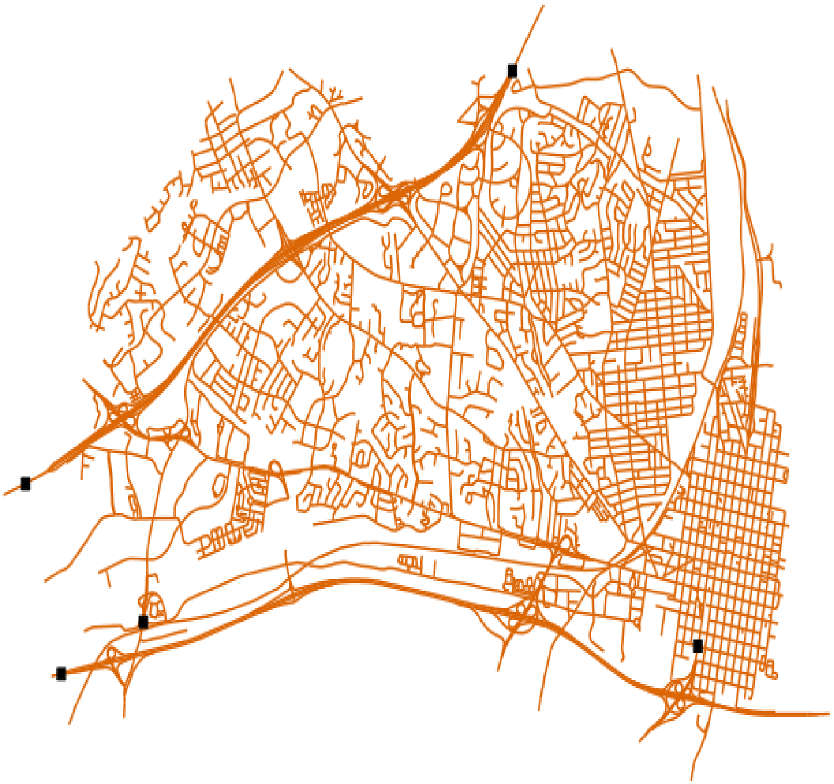
Implementation

Problem reduction

- Take all paths (p) with at least 5 cars per day
- Total flow: 239278 cars/day (62% of load)
- variables: 209785 (9%)
- constraints: 19731 (85%)

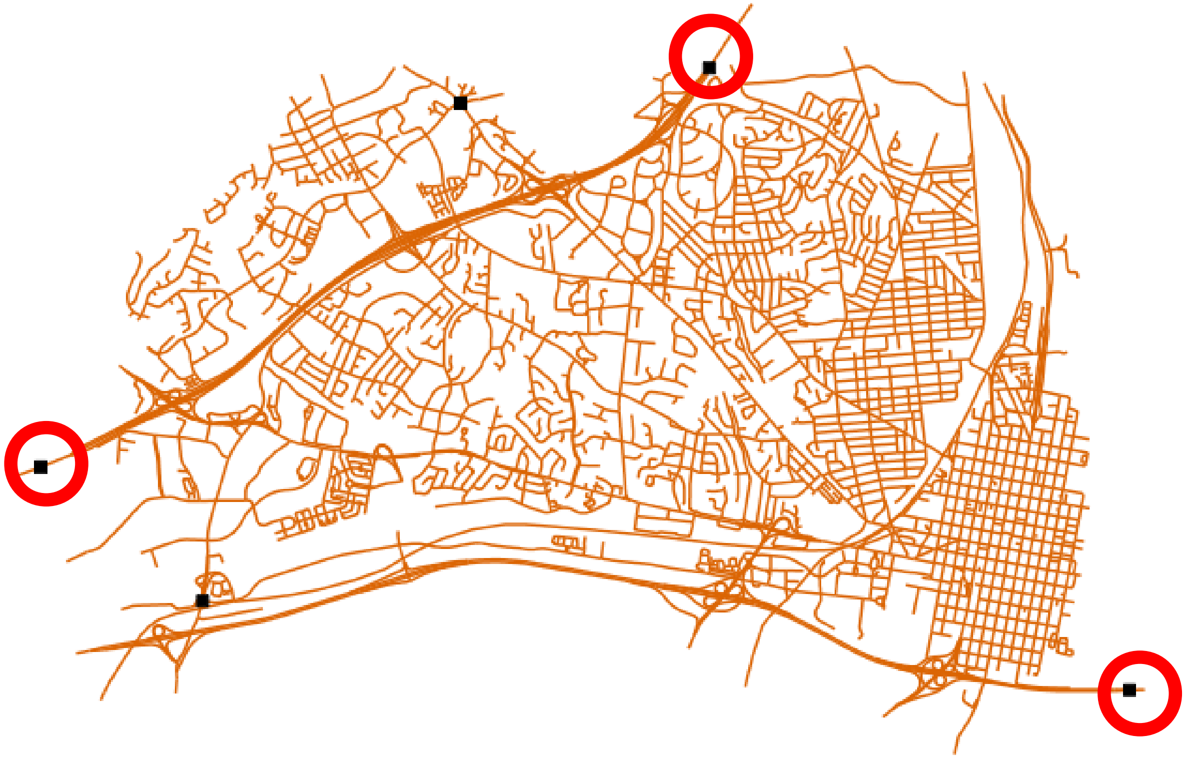
Results

Result: 5 facilities, no failures



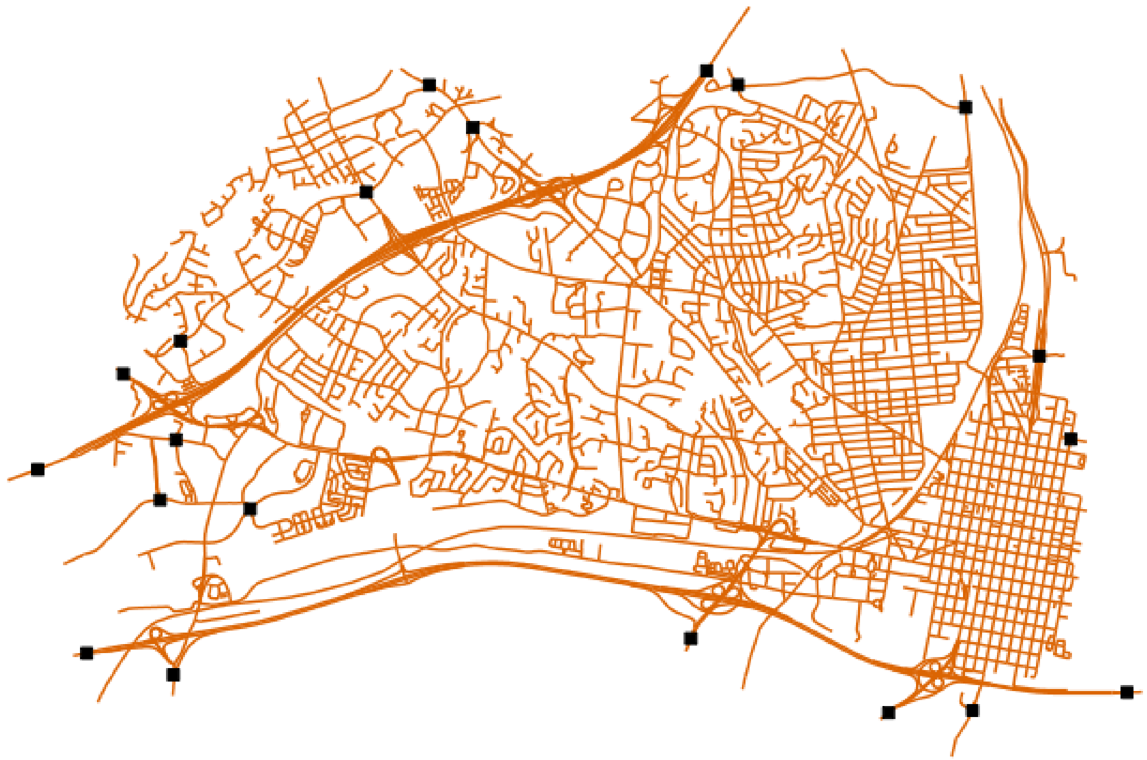
Results

Result: 5 facilities, node failures (5%)



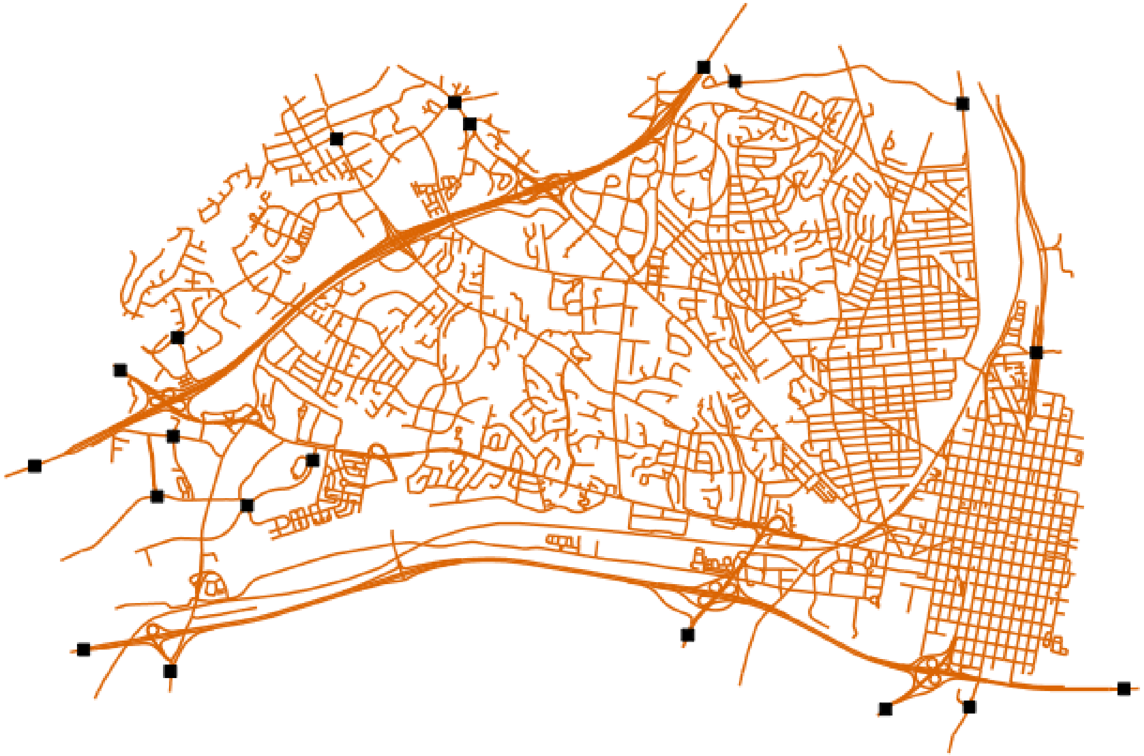
Results

Result: 20 facilities, no failures



Results

Result: 20 facilities, facility failures (5%)



Conclusions and perspectives

Achieving resilience in networked systems:

- operations research approach (integer programming)
- allows to mitigate failure upfront by design

Future:

- Re-routing: guide vehicles to alternative route/station
- Combined problem:
  Position facilities knowing that you can re-route cars